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For

METHOD AND APPARATUS FOR MONITORING OF SLURRY CONSISTENCY

by

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METHOD AND APPARATUS FOR MONITORING OF SLURRY CONSISTENCY

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of United States Provisional Patent Application Serial No. 60/486,387, filed July 11, 2003, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

This invention relates to supplying chemicals for manufacturing processes and, in particular, to an apparatus and a method for performing online monitoring of the consistency of a chemical slurry.

2. DESCRIPTION OF THE RELATED ART

The technology explosion in the manufacturing industry has resulted in many new and innovative manufacturing processes. Today's manufacturing processes, particularly semiconductor manufacturing processes, call for a large number of important steps. These process steps are usually vital, and therefore, require a number of inputs that are generally fine-tuned to maintain proper manufacturing control.

The manufacture of semiconductor devices requires a number of discrete process steps to create a packaged semiconductor device from raw semiconductor material. The various processes, from the initial growth of the semiconductor material, the slicing of the semiconductor crystal into individual wafers, the fabrication stages (etching, doping, ion implanting, chemical-mechanical planarization, or the like), to the packaging and final testing of the completed device, are so different from one another and specialized that the processes may be performed in different manufacturing locations that contain different control schemes and involve delivery of various materials from one site to another.

Advancements in process technology has allowed for more efficient processing of semiconductor wafers to produce integrated circuits in a more efficient and accurate manner. One important process is a chemical mechanical planarization (CMP) process that is used to process semiconductor wafers. There are various layers of films on a semiconductor wafer that may be polished and planarized using this process. The films that are processed may include silicon oxide, silicon nitride, aluminum fill, and/or tantalum nitride film. More recently, copper has been used to develop interconnects and other structures on semiconductor wafers. Generally, a copper film is polished in order to planarize the copper film placed upon a layer of the semiconductor wafer being processed. Processes such as oxide CMP and nitride CMP may be performed to polish copper layers.

The consistency of the chemicals that are used in performing various processes performed on semiconductor wafers, such as CMP processes, may become important in achieving consistent results. Many chemicals used for processes, such as CMP, are delivered in a slurry form. Often, copper slurry contains particles of aluminum oxide used as an abrasive agent in performing the CMP process. Additionally, the slurries may contain chemical mediums, such as benzotriazole, which may be used to protect the copper film from corrosion. Furthermore, other chemical agents, such as hydrogen peroxide, may be used as an oxidizing agent, atonalamean and other complexing agents. Disruption or changes in the physical characteristic of the slurry may cause errors and misprocessing of various processes, such as CMP processes, performed on the semiconductor wafers.

Process designers have attempted to provide a solution in an attempt to maintain the consistency of slurry. One solution offered by process designers involves a particle probe system, as described in U.S. Patent No. 6,275,290: "Chemical Mechanical Planarization (CMP) Slurry Quality Control Process and Particle Size Distribution Measuring Systems." U.S. Patent No. 6,275,290 describes a particle distribution probe which uses special processing including a modified Twomey/Chahine iterative convergence technique and a specially constructed sample cell to obtain particle size distribution measurements from optically dense slurries, such as the slurries used in the semiconductor industry for chemical mechanical planarization. Spectral transmission data is taken over the spectral range of 0.20-2.5 microns. In addition to the calculation of particle size distribution from the

measured transmitted light, the invention described in U.S. Patent No. 6,275,290 is claimed to assist in the detection of other fundamental causes of slurry degradation, such as foaming and jelling.

However, the technology provided by U.S. Patent No. 6,275,290 has various drawbacks. The technique described in U.S. Patent No. 6,275,290 is not a direct measure of suspended solids in a slurry; it only gives a qualitative measure of the change in suspended solids. Furthermore, if a slurry were undergoing a simultaneous change in the level of suspended solids and a change in particle size distribution, the method disclosed in U.S. Patent No. 6,275,290 would be unable to distinguish the root cause of such change, since the light transmission at various wavelengths specified in this patent would be affected by such changes. Hence, this method would not be an efficient and accurate quantifier of a change in suspended solids alone. Also, the presence of other species in the slurry, such as oxidizers (like H_2O2) and organic acids (like benzotriazole) will affect the light transmission at certain wavelengths in the method.

As described above, the consistency of the chemical product, *i.e.*, the slurry, the impurity levels, the amount of dissolved materials, *etc.*, are all factors that are to be within predetermined tolerance levels for proper operation of various processes that utilize these slurries, such as CMP processes. The state of the art generally lacks an efficient and accurate assessment of the slurry for use in various wafer-processing steps.

The present invention is directed to overcoming, or at least reducing, the effects of one or more of the problems set forth above.

SUMMARY OF THE INVENTION

In one aspect of the present invention, an apparatus for performing online monitoring of a physical characteristic of a process material, is provided. The apparatus of the present invention includes an optical source for providing an optical signal into a slurry. The apparatus also includes an optical sensor for detecting the optical signal. The apparatus of the present invention also includes a controller for determining whether a physical characteristic

of the slurry is within a predetermined tolerance level in an online manner, in response the optical signal.

In another aspect of the present invention, a method for performing online monitoring of a physical characteristic of a process material, is provided. A request to provide a slurry to a processing tool is received. The slurry is transported through a slurry transport unit, based upon the request, to the processing tool. An online monitoring of a physical characteristic of the slurry is performed. The online monitoring of the slurry includes analyzing an optical signal sent through the slurry to determine whether the physical characteristic of the slurry is within a predetermined level of tolerance.

In yet another aspect of the present invention, a system for performing online monitoring of a physical characteristic of a process material, is provided. The system of the present invention includes a process chemical unit for providing a slurry. The system also includes a processing tool for performing a process upon a semiconductor wafer using the slurry. A slurry transport conduit transports the slurry from the process chemical unit to the processing tool. The slurry transport conduit includes an optical source for providing an optical signal into the slurry, and an optical sensor for detecting the optical signal. The system of the present invention also includes a slurry analysis unit for performing an online analysis of the slurry in the slurry transport conduit. The slurry analysis unit includes a controller to determine whether a physical characteristic of the slurry is within a predetermined tolerance level in an online manner, in response to the optical signal.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be understood by reference to the following description taken in conjunction with the accompanying drawings, in which the leftmost significant digit(s) in the reference numerals denote(s) the first figure in which the respective reference numerals appear, and in which:

Figure 1 illustrates a block diagram of a system for monitoring a physical characteristic of a material used for a manufacturing process, in accordance with one embodiment of the present invention;

Figure 2 illustrates a more detailed block diagram depiction of a slurry analysis unit of Figure 1, in accordance with one embodiment of the present invention;

Figure 3 illustrates a more detailed block diagram depiction of a slurry transport conduit of Figures 1 and 2, in accordance with one embodiment of the present invention;

Figure 4 illustrates a graph that depicts the percentage of solids detected by the system of the present invention based upon the operation of a pump, in accordance with one embodiment of the present invention;

Figure 5 illustrates a graph that depicts the percentage of solids detected by the system of the present invention based upon the addition of a liquid, in accordance with one embodiment of the present invention;

Figure 6 illustrates a more detailed block diagram depiction of the system, in accordance with one illustrative embodiment of the present invention; and

Figure 7 illustrates a flowchart that provides a method for monitoring a physical characteristic of a material used for a manufacturing process, in accordance with one illustrative embodiment of the present invention.

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

Illustrative embodiments of the invention are described below. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developer's specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

Embodiments of the present invention provide for monitoring a physical characteristic (*e.g.*, the consistency) of a material, such as a chemical slurry, used for a manufacturing process. For example, the consistency of a chemical slurry used for a chemical-mechanical planarization (CMP) process is monitored in an online fashion (*e.g.,* substantially real time or a near real time manner). By utilizing embodiments of the present invention, slurry that comprises a chemical compound used in semiconductor wafer processing, may be monitored using various sensors. Data from these sensors may be analyzed by a slurry analysis unit, which may be used in a feedback manner to affect the physical nature of the slurry.

Embodiments of the present invention provide for utilizing an optical source that provides an optical stimulation within the slurry, and an optical sensor to detect the resultant optical signal. The optical signal is used to monitor the physical characteristics of the slurry, such as the percentage of solids in the slurry. Additionally, other physical sensors may also be used to monitor various other physical characteristics of the slurry (*e.g.*, the flow characteristics of the slurry, the pressure experienced by the slurry, *etc.*). Data from the optical sensors and/or the physical sensors may be utilized to perform a feedback analysis of the physical nature of the slurry.

Embodiments of the present invention provide for a substantially real time analysis of the slurry. Embodiments of the present invention provide for a method and apparatus for performing a feedback correction directed to modifying the nature of the slurry to have

physical characteristics that are generally within predetermined tolerances for use in semiconductor wafer processing, such as CMP processes.

Turning now to Figure 1, a system 100 that performs a slurry analysis in accordance with embodiments of the present invention is illustrated. In one embodiment, the system 100 comprises a process chemical unit 110, a processing tool 120, which may include a set of processing tools, a slurry analysis unit 140, and a slurry transport conduit 130, which is capable of transporting chemical compounds. The slurry transport conduit 130 is capable of transporting process chemical compounds from the process chemical unit 110 to the processing tools 120. The process chemical unit 110 may store chemicals, mix, or prepare chemicals for use by various processes performed by the processing tools 120.

The slurry transport conduit 130 may comprise various mechanical and electrical devices designed to generate pressure and/or other stimuli to transport the chemical compound/slurry from the process chemical unit 110 to the processing tools 120. The slurry transport conduit 130 may comprise various sensors (described and illustrated in various Figures and descriptions provided herein) that provide data to the slurry analysis unit 140. The slurry analysis unit 140 is capable of analyzing data from various sensors in an online and/or an off-line manner. The slurry analysis unit 140 is also capable of providing feedback signals to affect the physical characteristics of the slurry in the slurry transport conduit 130.

Turning now to Figure 2, a more detailed illustration of the slurry analysis unit 140 in accordance with one embodiment of the present invention is illustrated. The slurry analysis unit 140 may comprise an optical source 210 that is capable of providing an optical signal in a predetermined position, such as position a, in the slurry transport conduit 130. The slurry analysis unit 140 also comprises an optical sensor 220 that may be positioned in a predetermined position b in the slurry transport conduit 130. The optical signal provided by the optical source 210 is affected by the solids in the slurry. By examining the optical source, the percentage of solids in the slurry may be determined. In one embodiment, an extension of the optical source 210 and the optical sensor 220 may be placed within the slurry transport conduit 130. In an alternative embodiment, the optical source 210 and the optical sensor 220

may be physically placed in the slurry transport conduit 130. In either case, data from an optical sensor 220 is received by the slurry analysis unit 140.

Additionally, the slurry analysis unit 140 may be associated with one or more physical sensors 250 that may be placed within the slurry analysis unit 140 with an extension of such physical sensors 250 placed within the slurry transport conduit 130. In an alternative embodiment, the physical sensors 250 may actually be placed within the slurry transport conduit 130 and is capable of providing data to the slurry analysis unit 140. Data from the physical sensors 250 and the optical sensors 220 is sent to a computer system 240, which is capable of analyzing the data. The computer system 240 may determine the physical characteristics of the slurry in the slurry transport conduit 130. The computer system 240 may include a variety of types of computer systems, such as an PC (IBM® compatible computer), an Apple® computer, a mainframe, a network computer, or the like.

The physical characteristics determined by the slurry analysis unit 140 may include various characteristics, such as the percentage of solids in the slurry, the pressure experienced by the slurry, the flow characteristics (*e.g.*, flow rate) of the slurry, and the like. For example, the slurry may start to settle at the bottom of the slurry transport conduit 130, thereby affecting the data relating to the percentage of solids in the slurry. Some slurries may have physical characteristics such that without proper movement of the slurry, alumina particles, for example, may become settled at the bottom. Additionally, various chemical mediums may be dispersed within the slurry transport conduit 130. The pH of the chemical medium may be used to decrease the possibility of settling of various particles, such as alumina. However, a certain pH may be required for proper operation of the processing of semiconductor wafers where the slurry is used. Additionally, proper mixing of the slurry may be important in the proper utilization of the slurry for processing semiconductor wafers, *e.g.*, CMP processes performed on semiconductor wafers.

Turning now to Figure 3, one implementation of various apparatus associated with embodiments of the present invention that are implemented into the slurry transport conduit 130, is illustrated. An optical source 210 may be placed in a predetermined location within the slurry transport conduit 130. For example, the optical source 210 may be placed near the

center of the slurry transport conduit 130 where a first length (ℓ_1) 330 and a second length (ℓ_2) 340 is used to displace the optical source 210 from the top and bottom of the slurry transport conduit 130. Similarly, the optical sensor 220 may also be displaced from the top and bottom portion of the slurry transport conduit 130 by the length (ℓ_3) 350 and the length (ℓ_4) 360. Additionally, the distance between the optical source 210 and the optical sensor 220 may be displaced by the length (ℓ_5) 370, which is strategically predetermined for improving data accuracy.

Furthermore, the physical sensors 250, which senses various physical characteristics of the slurry and/or the slurry transport conduit 130, may be positioned within the conduit 130. For example, the physical sensors 250 may include sensors that measure the pressure in the slurry transport conduit 130, the flow characteristics (*e.g.*, the velocity of the flow) of the slurry in the slurry transport conduit 130, and the like. Additionally, the slurry transport conduit130 may comprise various pumps 378 and/or valves 380 that control the movement of the slurry in the slurry transport conduit 130. Based upon the calculations of physical characteristics of the slurry, feedback signals may be sent to the pumps 378 and/or the valves 380 to adjust the flow of the slurry in the slurry transport conduit 130. The velocity of the slurry flow and the pressure inside the slurry transport conduit 130 are generally maintained such that the possibility of particles settling at the bottom of the slurry transport conduit 130 is reduced.

Turning now to Figure 4, a diagram illustrating the percentage of solids within the slurry versus the time the slurry is in the slurry transport conduit 130 is illustrated. Initially, at region 410 of the graph, the sensors 220, 250 may detect that the solid contents in the slurry is negligible as the pumps 378 begin operation and the slurry begins to re-circulate. At low pump speeds, the region 420 is initiated and as the pump speed becomes greater a certain level of solids within the slurry is maintained. In other words, in the middle of the slurry transport conduit 130, a certain amount of solids are mixed within the slurry such that a predetermined percentage of solids are maintained in the slurry. However, if the pumps 378 were to be stopped (see region 430), the particles in the slurry may begin to settle. This would cause the percentage of solids in the slurry to decline, which may be detected by the sensors 220, 250 (see region 440 in Figure 4). At region 450, the slurry essentially settles at

the bottom of the slurry transport conduit 130, and the sensor 220, 250 will detect that the percentage of solids is very low.

As illustrated in Figure 5, the percentage of solids in relation to time may vary based upon the addition of various liquid compounds, such as H_2O_2. The region 560 in the graph illustrated in Figure 5, shows a particular level of percentage of solid in the slurry detected by the optical sensor 220 in the slurry transport conduit 130. However, at point 560, 2% of H_2O_2, for example, may be added to the slurry, thereby reducing the percent of solid detected by the sensor 220, as indicated by the graph in Figure 5. This causes a decline in the percent of solid in the slurry. At region 570, an additional 0.1% of H_2O_2 is added to the slurry, thereby further reducing the percent of solid detected in the slurry transport conduit 130. Likewise, at points 580 and 590, an additional 0.1% of H_2O_2 are added respectively, thereby even further reducing the percent of solid in the slurry. Therefore, the percentage of solid variation may be controlled in the slurry transport conduit 130 by adding various compounds such as H_2O_2. Since the physical characteristics of the slurry may be detected in an online fashion, an online feedback control of the slurry may be implemented to modify the characteristics of the slurry.

Turning now to Figure 6, a more detailed block diagram illustration of the system 100 in accordance with embodiments of the present invention is illustrated. In one embodiment, the slurry transport conduit 130 may be fitted with various sensors, such as the optical sensor 220, a pressure sensor 620, and a flow sensor 630. The optical sensor 220 is capable of receiving affected optical signals provided by the optical source 210. The pressure sensor 620 is capable of detecting the online pressure in the slurry transport conduit 130 in a real time manner. Therefore, a real time evaluation of the pressure experienced by the slurry may be quantified. Additionally, the flow sensor 630 is capable of detecting the flow rates (*i.e.*, the flow velocity) of the slurry flow in the slurry transport conduit 130. The flow rate of the slurry, the pressure experienced by the slurry, the amount of liquid compound added to the slurry may generally influence the percentage of solids in the slurry detected by the system 100.

The slurry analysis unit 140 may comprise an optical sensor interface 640 that is capable of receiving a signal from the optical sensor 220 and generating a decipherable signal, such as a

digital signal, that represents optical data. The slurry analysis unit 140 may also comprise a pressure sensor interface 650 that receives data from the pressure sensor 620 and generates a decipherable pressure signal, digital or analog. Similarly, a flow sensor interface 660 in the slurry analysis unit 140 is capable of receiving a signal from the flow sensor 630 and generating a decipherable signal, analog or digital, that represents a flow velocity of the slurry in the slurry transport conduit 130. The slurry analysis unit 140 may comprise a sensor data analysis unit 670 that is capable of performing an analysis of the optical, pressure, and/or the flow rate data received by the slurry analysis unit 140.

The sensor data analysis unit 670 may have access to various theoretical calculations of slurry data, optimum pressure and flow-velocities for maintaining desirable physical characteristics that are tailored to particular slurries that are used for various processes. The sensor data analysis unit 670 is capable of correlating various pressure and/or flow-velocity to the percentage of solids in the slurry, as determined from the analysis of the optical data. This correlation may be compared to stored data that provides for acceptable tolerances from the library 675. For particular types of slurry, a predetermined range of pressure, flow-velocity and percent solid count is desirable. The percent solid count may relate to the percentage of solids in the middle of the slurry transport conduit 130. The middle of the slurry transport conduit 130 is of interest, since examining the characteristics in the middle of the conduit 130 generally takes into account for any possible settling of various particles in the slurry. Based upon such an analysis, data may be generated as to the state of the slurry and whether it is within predetermined tolerance levels.

As illustrated in Figure 6, the data relating to whether the state of the slurry is within predetermined tolerance levels may be sent to a feedback unit 680. The feedback unit 680 is capable of determining feedback signals based upon the characteristics of the slurry determined by the sensor data analysis unit 670. The feedback signals are generally directed to compensating or adjusting the physical characteristics of the slurry, to place it within predetermined tolerance ranges. Based upon signals from the feedback unit 680, a flow controller 690 may determine what types of adjustment may be needed. For example, as part of the adjustments, the operation of various pumps 378 and valves 380 may be adjusted, and additional compounds, such as H_2O_2, may be added to the slurry.

The data from the flow controller 690 may then be sent from the flow controller 690 to a flow control unit 695, which is capable of affecting the operation of various components in the slurry transport conduit 130. For example, the flow control unit 695 may be affect the operation of the pumps 378, the valves 380, or affect liquid compounds that may injected into the slurry in the slurry transport conduit 130. Therefore, the sensor data is analyzed and feedback data may be generated in a real time, near real time, or online fashion, such that the flow control unit 695 may affect the consistency and the physical characteristics of the slurry in the slurry transport conduit 130. These adjustments may be made in an online, substantially real time manner. Therefore, the slurry received by the processing tools 120 may be of a quality that is within predetermined tolerance levels such that the processes, such as CMP processes, performed by the processing tool 120, is more efficient and accurate.

The sensor data analysis unit 670, the feedback unit 680, the flow controller 690 and the flow control unit 695 may be hardware, software, or firmware components, or alternatively, a combination thereof. Various computer programs or portions of computer programs, PC cards, and software components may be utilized to perform the various functions of the slurry analysis unit 140.

Turning now to Figure 7, a method in accordance with embodiments of the present invention is illustrated. Generally, the system 100 receives a signal to provide a chemical/slurry for use in processing semiconductor wafers (block 710). Based upon such a request, the system 100 provides the chemical/slurry to the processing tools 120 via the slurry transport unit 130 (block 720). Various pressures and velocities are calculated for optimum delivery of the slurry, while maintaining desired physical characteristics of the slurry.

The system 100 also performs an online monitoring of the slurry (block 730). For example, the system 100 may analyze the optical characteristics of the slurry to determine whether a desirable percentage of solids in the slurry are present at various areas (*e.g.*, the middle portion) of the slurry transport conduit 130. Additionally, the system 100 may also analyze other physical characteristics of the slurry, such as the pressure experienced by the slurry and/or the flow rate of the slurry. Based upon the online monitoring of the slurry, the system

100 generally correlates the various physical characteristics of the slurry (block 740). For example, the system 100 correlates the flow rate of the slurry to the percentage of solid in the middle of the slurry transport conduit 130.

The system 100 makes a determination whether the physical characteristics are within predetermined tolerance levels (block 750). In other words, the system 100 determines whether the slurry contains adequate percent solid at various points of the slurry in the slurry transport conduit 130. These predetermined tolerance levels are generally calculated specifically for the type of process being performed, the characteristics of the type of chemicals and abrasives in the slurry, and the like. The predetermined tolerance levels may be stored in the library 675 for access and comparison by the system 100.

When the system 100 determines that the physical characteristics of the slurry are within predetermined tolerance levels, the system 100 generally continues to perform online monitoring of the slurry as indicated in Figure 7. The frequency of the online monitoring of the physical characteristics of the slurry may be variable, and may depend on the specific type of slurry used for particular processes (*i.e.*, the particular type of CMP being implemented).

If the system 100 determines that the physical characteristics of the slurry are not within predetermined tolerance levels, the system 100 performs corrective action based upon the correlation of the physical characteristics and tolerance levels (block 760). The corrective actions may include various tasks, such as adjusting the flow rate in the slurry transport conduit 130, adjusting the pressure experienced by the slurry, further mixing of the slurry, and/or the like. The method steps illustrated in Figure 7 are performed to obtain adequate and acceptable physical characteristics of the slurry when delivering it from the process chemical unit 110 to the processing tools 120. Therefore, the chemical/slurry used by the processing tools 120 may be within predetermined tolerance levels, thereby providing for more uniform quality of processed semiconductor wafers.

The particular embodiments disclosed above are illustrative only, as the invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art

having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the invention. Accordingly, the protection sought herein is as set forth in the claims below.